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Green Subsidies in Agriculture: Estimating the Adoption Costs of Conservation Tillage from Observed Behavior (Revised)

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Abstract

Because of payoff uncertainties combined with risk aversion and/or real options, farmers may demand a premium in order to adopt conservation tillage practices, over and above the compensation for the expected profit losses (if any). We propose a method of directly estimating the financial incentives for adopting conservation tillage and distinguishing between the expected payoff and premium of adoption based on observed behavior. We find that the premium may play a significant role in farmers' adoption decisions.

Keywords: adoption subsidies, Conservation Security Program (CSP), conservation tillage, risk premium.

GREEN SUBSIDIES IN AGRICULTURE: ESTIMATING THE ADOPTION COSTS OF CONSERVATION TILLAGE FROM OBSERVED BEHAVIOR

The provision of the Conservation Security Program (CSP) in the 2002 Farm Security and Rural Investment Act (the 2002 farm bill) marks a potentially significant change in the direction of U.S. environmental policy with respect to agriculture. Rather than focusing on incentives to retire environmentally sensitive land from production, the CSP targets changes in agricultural practices on working lands. Specifically, the act authorizes the U.S. Department of Agriculture to make payments to farmers who adopt conservation practices, such as conservation tillage. To predict farmer participation and the cost of this program, it is important to estimate quantitatively farmers' incentives to adopt such practices.

The adoption of conservation practices does not always lead to a reduction in farmers' profits. In fact, even without any government subsidy, on average over 36 percent of U.S. acres are in conservation tillage (CTIC 2000). Nevertheless, to the extent that an individual farmer ignores the social benefits of conservation practices, the adoption rate is likely to be lower than socially optimal. Further, even when conservation practices can raise farmers' expected profits, they may be reluctant to adopt because the practices may be riskier. They may require a premium to adopt if they are risk averse, because the net payoff under conservation tillage is often more uncertain (Klemme 1985; Fox et al. 1991). Further, the premium may arise because adoption involves sunk investments (e.g., in human or physical capital) and real options are present (Arrow and Fisher 1974). Then, even if they are risk neutral, farmers may have incentives to wait for more information about the payoffs of both tillage practices before committing to investments. Under either or both cases, farmers adopt only if the additional profit of conservation practices overcomes the premium.

There is a large body of literature devoted to the incentives of farmers to adopt conservation practices and new technologies in general (Sunding and Zilberman 2000 provides a review). The incentives are found to depend qualitatively on soil quality, crops grown, and farmer characteristics such as age and education. In spite of this literature, there exists little empirical evidence on the incentive payments (or subsidies) that would be needed to induce farmers to adopt conservation practices (and new technologies in general). Thus, there is little empirical evidence for evaluating the effectiveness of the CSP or for considering the consequences of setting alternative subsidy levels.

The reason for this omission is that most of the studies employ discrete choice methods that allow coefficient estimates to be recovered only up to a multiplicative constant. Thus, though probabilities of adoption can be estimated, these estimates cannot be readily converted into dollar compensation levels. Consequently, adoption subsidies have been estimated mostly through stated preference methods (Lohr and Park 1995; Cooper and Keim 1996; Cooper 1997).[1]

This paper contributes to the literature in several ways. First, we adopt a modeling strategy based on the contingent valuations literature that allows for full recovery of the structural coefficients and hence gives us the ability to compute directly the subsidies needed for adoption. Pautsch et al. (2001) apply a simple version of this model to examine the potential for carbon sequestration in agricultural soils. Here, we develop a richer version where we incorporate an adoption premium related to uncertainty in addition to changes in expected profit. Second, we decompose the subsidy into two components: the profit loss (or gain) from adoption and the premium associated with uncertainty. In so doing, we confirm the arguments of agronomists and extension agents that conservation tillage pays (Jolly, Edwards, and Erbach 1983; Setia and Osborn 1989; Fox et al. 1991; Stonehouse 1995): on average in our sample, a farmer gains from adoption. However, the adoption premium may exceed the profit gain, and consequently the farmer may require a subsidy to adopt the practice. We study the significance and empirical magnitude of these quantities.

Finally, based on the estimated subsidies, we calculate the “supply curve” of conservation tillage and analyze the role of the subsidies in improving environmental performance and as a tool of income transfers to farmers. We find that a significant part of the subsidy (or conservation payments) will be income transfers to existing and low-cost adopters. Thus, while a program like the CSP can be expected to yield an increase in the environmentally friendly practice of conservation tillage, a large percentage of the funds will be transferred to producers for whom adoption has already occurred. Our results provide some of the first empirical evidence on the potential effectiveness of a program like the CSP in encouraging adoption of conservation tillage.

The Adoption Model

We begin by describing the theoretical justification for the existence of an adoption premium, and why the premium relates directly to payoff uncertainties, thereby allowing separate estimation of the premium and net returns of conservation tillage. Let π_1 represent the expected annual net return from using conservation tillage while π_0 is that from using conventional tillage and σ_1^2 and σ_0^2 are the variances of the two returns. Consider first a simple case where every year farmers can freely change their farming practices between the two choices. If they are risk averse, standard utility theory indicates that they use conservation tillage if and only if $\pi_1 - R_r(\sigma_1^2, \mathbf{z}_r) \geq \pi_0 - R_r(\sigma_0^2, \mathbf{z}_r)$ or $\pi_1 - \pi_0 \geq R_r(\sigma_1^2, \mathbf{z}_r) - R_r(\sigma_0^2, \mathbf{z}_r)$, where $R_r(\bullet)$ is the risk premium associated with each practice, and $\mathbf{z}_r$ is the set of variables that affect the risk premium, such as farm income and other individual attributes. Typically $\sigma_1^2 > \sigma_0^2$, either because farmers have more experience with conventional till or because of the agronomic characteristics of the two practices (Klemme 1985; Fox et al. 1991). Then π_1 must exceed π_0 by a strictly positive premium for farmers to adopt conservation tillage.

More realistically, adopting a new tillage practice requires investment in physical and human capital. Moreover, conservation tillage usually leads to lower yields in early years before soil nutrients build up. The lost profit in these years is sunk because it cannot be recovered by reverting to conventional tillage. Given the uncertainties and the lost profits, farmers may be reluctant to adopt conservation tillage and will adopt only when they are especially “sure” that adoption will be profitable. Specifically, there is value in delaying the adoption decision until farmers have acquired enough information about the practice to be sure that the likelihood of unprofitable adoption is sufficiently low. In this case, farmers adopt only when π_1 exceeds π_0 by the option value or premium, $R_p(\sigma_1^2, \sigma_0^2, \mathbf{z}_p)$, where $R_p(\bullet)$ is increasing in the first two arguments, and $\mathbf{z}_p$ is the relevant explanatory variable. This reasoning does not depend on the risk attitude of farmers and is a standard result in the real options literature (Arrow and Fisher 1974; Dixit and Pindyck 1994).

Note that both sources of the adoption premium (R_r and R_p) depend on the existence of uncertainties in the returns of conventional and conservation tillage practices, as well as on income and farmer characteristics. For example, the existence of sunk costs of adoption alone does not generate a premium. If farmers know with certainty the future streams of returns under the two practices, their decision will depend only on the two net present values. In this case, the sunk costs simply enter the streams of returns and affect the NPVs alone, and thus they will not lead to any additional adoption premium.

In summary, because of risk aversion or real options, farmers typically demand a premium for adopting conservation tillage. That is, they adopt if and only if $\pi_1 - \pi_0 \geq P(\sigma_1^2, \sigma_0^2, \mathbf{z})$, where $P(\sigma_1^2, \sigma_0^2, \mathbf{z}) \equiv [R_r(\sigma_1^2, \mathbf{z}_r) - R_r(\sigma_0^2, \mathbf{z}_r)] + R_p(\sigma_1^2, \sigma_0^2, \mathbf{z}_p)$. The premium is zero when both variances are zero. This latter fact is the critical feature that allows estimation of the premium to be separate from that of the net returns of conservation tillage.

We turn now to the modeling strategy for describing farmers' decisions to adopt conservation tillage. In the standard setting, farmers are expected to adopt conservation tillage if the anticipated profit from adoption exceeds that from continuing with conventional practices, that is, when $\pi_1 \geq \pi_0$. The farmers' profit functions are assumed known to the farmers but unobservable to the researcher. An additive error is incorporated to reflect the researcher's omission of relevant variables or misspecification of the net returns functions. An expression for the probability of adoption from the researcher's perspective can be then written as

$$\Pr\left[adopt\right] = \Pr\left[\pi_1 \geq \pi_0 + \sigma\varepsilon\right], \tag{1}$$

where ε is typically a standard normal or logistic error and σ is the associated standard deviation multiplier. We write the error term in this somewhat nonstandard way to explain more easily the limitation of this form of the model. The next step is to specify a functional form for the difference in the net returns, typically linear in explanatory variables; for example, $\pi_1 - \pi_0 = \boldsymbol{\delta}\mathbf{y}$, where $\mathbf{y}$ is a vector of explanatory variables and $\boldsymbol{\delta}$ is a vector of coefficients.

Two limitations in this model restricts the full understanding of adoption decisions. First, there is no explicit formalization of the existence of the premium needed to induce adoption. Second, and even more critical for estimating the financial incentives needed to induce adoption, the coefficients on the net returns expression can only be estimated up to the multiplicative constant, σ. To see this, write the probability of adoption as

$$\begin{aligned}\Pr\left[adopt\right] &= \Pr\left[\pi_1 \geq \pi_0 + \sigma\varepsilon\right] \\ &= \Pr[\boldsymbol{\delta}\mathbf{y} \geq \sigma\varepsilon] \\ &= \Pr[\varepsilon \leq \frac{\boldsymbol{\delta}\mathbf{y}}{\sigma}].\end{aligned} \tag{2}$$

This formulation makes clear the point that is well known among practitioners of discrete choice models: only estimates of the ratios of the coefficients to the standard deviation can be recovered. Consequently, the changes in net returns associated with adoption of conservation tillage cannot be estimated. Analysts must be satisfied with predictions of qualitative changes such as identifying what characteristics of farmers will increase the likelihood of adoption.

Here we propose and implement a conceptual model that both (*a*) explicitly incorporates an adoption premium to reflect risk aversion and real options, and (*b*) allows recovery of an estimate of σ, thereby allowing recovery of the individual parameter values. Specifically, we assume that an individual farmer will adopt conservation tillage when $\pi_1 \geq \pi_0 + P,$ where P is the premium. Again, an additive error is used to represent omitted variables or misrepresentation of the net returns statement by the researcher, and π_1 is assumed linear in explanatory variables. However, we assume that the expected net returns from conventional tillage are known to the farmer and focus on modeling the returns to conservation tillage as a function of explanatory variables. Thus, we write the probability of adoption as

$$\begin{aligned}\Pr\left[adopt\right] &= \Pr\left[\pi_1 \geq \bar{\pi}_0 + P + \sigma\varepsilon\right] \\ &= \Pr[\boldsymbol{\beta}\mathbf{x} \geq \bar{\pi}_0 + P + \sigma\varepsilon] \\ &= \Pr[\varepsilon \leq \frac{\boldsymbol{\beta}\mathbf{x}}{\sigma} - \frac{\bar{\pi}_0}{\sigma} - \frac{P(\sigma_1^2, \sigma_2^2, \mathbf{z})}{\sigma}],\end{aligned} \tag{3}$$

where $P(\sigma_1^2, \sigma_2^2, \mathbf{z})$ represents the premium as a function of its explanatory variables, and the bar on $\bar{\pi}_0$ denotes that this variable is known. Note that $\boldsymbol{\beta}\mathbf{x}$ represents the expected net returns to conservation tillage, and not the difference in returns between the two practices (represented by $\boldsymbol{\delta}\mathbf{y}$ above).

In this formulation, recovery of the standard deviation multiplier σ is straightforward, as it will be simply the inverse of the coefficient estimated on $\bar{\pi}_0$. Thus, by adding information to the model in the form of the expected net profits from conventional tillage, it is possible to estimate the standard error, in turn allowing recovery of the specific parameter values for $\boldsymbol{\beta}$.[2]

Further, it seems reasonable to assume that farmers understand well the expected return from adoption of conventional tillage, as this practice has been used widely over a long period. Thus, farmers have substantial experience both in using conventional tillage and in predicting its mean profitability (e.g., in making annual planting decisions).

Turning now to the premium function, note that the theoretical basis for the presence of an adoption premium requires the presence of profit uncertainties of the two tillage practices. Although these uncertainties may affect the premium differently under risk aversion and real options, we focus on the magnitude of the premium and how it depends on the uncertainties rather than focusing on attempting to identify the source. Since the data set we use is cross-sectional and because of well-established agricultural input and output markets, we see no reason for the farmers in our sample to face varying price uncertainty across the two practices. Thus, only yield uncertainties vary across the sample and are modeled in this study. This observation provides important guidance in specifying the empirical model, as it implies that the adoption premiums should depend on variables related to yield uncertainty as well as to farmer characteristics that may define how uncertainty translates into adoption premiums. Because the expected net return π_1 does not depend on the uncertainties, σ_1^2 and σ_2^2 do not enter the explanatory variables x.

Again, the connection of the premium to uncertainty in returns provides the theoretical foundation for separating the premium from net returns in the estimation model.

Data and Notation

The study region is the state of Iowa. Summary statistics and definitions of the explanatory variables are given in Table 1. All data are for the 1992 growing season.[3] The crops in the analysis are corn, soybeans, wheat, and hay.

The primary data source is a random sample drawn from the National Resource Inventory (NRI) (USDA/NRCS 1994). The NRI provides information on the natural resource characteristics of the land (soil properties and slope), the crop grown (1992 and 1991 seasons), and the farming practices used by the producer. The data are statistically reliable for national, state, and multi-county analysis of non-federal land (Nusser and Goebel 1997). Thus, it is reasonable to assume that the Iowa NRI sample is representative of Iowa agricultural land. For the purposes of our estimation, we treat each NRI point as representing a producer.

NRI also provides information on whether conservation tillage is used. The tillage is defined as conservation if at least 30 percent of the soil surface is covered by plant residue after planting or at least 1,000 pounds per acre of flat, small-grain residue equivalent are on the surface during the critical erosion period (USDA/NRCS 1994). Because an increase in the amount of crop residue cover on the soil surface tends to keep soils cooler, wetter, less aerated, and denser, conservation tillage is favored on sloping and better-drained soils (e.g., Allmaras and Dowdy 1985). As seen from Table 1, 63 percent of Iowa cropland is worked using conservation tillage.

To form our complete data set, we supplement the NRI data with constructed net returns to conventional tillage, climate, and farm operator characteristics data. We constructed $\bar{\pi}_0$ of each NRI sample point through farm budget analysis, specifically by combining county-specific average yield data during the 1991–92 period (USDA/NASS 1994), state-specific price data in 1992 (USDA/NASS 1999a), and region-, tillage-, and rotation-specific cost data from Mitchell (1997). As shown in Table 1, when calculating $\bar{\pi}_0$, we grouped together the crops other than corn and soybeans to account for the somewhat idiosyncratic nature of these crop choices (over 90 percent of Iowa cropland is

TABLE 1. Definition of variables and summary statistics

Notation	Description	Units	Sample Mean	Sample St. Dev.
	Conservation tillage (1-yes, 0-no)	Number	0.63	0.48
I_{cn}	Corn (1-corn, 0-soybeans or other crop)	Number	0.57	0.50
$\bar{\pi}_{0,cn}$	Net returns to conventional tillage, corn[a]	$ per acre	145	23
$\bar{\pi}_{0,sb}$	Net returns to conventional tillage, soybeans[b]	$ per acre	109	14
$\bar{\pi}_{0,oth}$	Net returns to conventional tillage, other crops [c,d]	$ per acre	93	43
SLOPE	Land slope	Percent	4.1	3.9
PM	Soil permeability	Inches per Hour	1.7	2.2
AWC	Soil available water capacity	Percent	18.5	2.8
TMAX	Mean of daily maximum temperature during the corn growing season	Fahrenheit	78.7	1.8
TMIN	Mean of daily minimum temperature during the growing season	Fahrenheit	55.6	2.0
PRECIP	Mean of daily precipitation during the growing season	Inches	0.141	0.012
σ_{precip}	Standard deviation of daily precipitation during the growing season	Inches	0.331	0.027
OFFFARM	Proportion of operators working off-farm to the total number of farm operators in the county	Number	0.471	0.055
TENANT	Proportion of harvested cropland operated by tenants to the total county harvested cropland	Number	0.199	0.050
AGE	County average farm operator age	Years	50.2	1.8
MALE	Proportion of male operators to the total number of farm operators in the county	Number	0.9774	0.0096
FARMSIZE	County average farm size	Acres	330	61

Note: Total observations are 1,339.
[a] 762 observations.
[b] 475 observations.
[c] Wheat or hay.
[d] 102 observations.

planted in corn or soybeans). The variable I_j is an indicator function for crops—j = cn (corn), sb (soybeans), oth (other)—with $I_j = 1$ if crop j is grown and $I_j = 0$ otherwise.

To put together climatic data for the crop growing seasons (as reported in USDA/NASS 1997), we assigned each NRI point to a weather station based on the county of location, and used 1975–94 weather station data provided by the National Climatic Data Center (Earthinfo 1995) to construct temperature and precipitation data (TMAX, TMIN, PRECIP, and σ_{precip}). The intertemporal standard deviation of precipitation σ_{precip} was calculated as the standard deviation of the daily precipitation during the growing season over the years 1975–94. Thus, it captures both the within-season and cross-season variations. County average indicators of farm operator characteristics (OFFFARM, TENANT, AGE, MALE, and FARMSIZE) were constructed from the 1992 Census of Agriculture data (USDA/NASS 1999b).

Model Specification and Estimation Results

The estimation models are variations of the following basic specification of the probability of adopting conservation tillage:

$$\Pr\left[adopt\right] = \Pr\left[\pi_{1,j} \geq \bar{\pi}_{0,j} + P_j\right], \quad j = cn, sb, oth, \tag{4}$$

where

$$\begin{aligned}\pi_{1,j} = {} & \beta_{0,cn} \cdot I_{cn} + \beta_1 \cdot SLOPE + \beta_2 \cdot PM + \beta_3 \cdot AWC + \beta_4 \cdot TMAX + \beta_5 \cdot TMIN + \beta_6 \cdot PRECIP \\ & + \beta_7 \cdot TENANT + \beta_8 \cdot OFFFARM + \beta_9 \cdot AGE + \beta_{10} \cdot MALE + \beta_{11} \cdot FARMSIZE \\ & + \sigma_\varepsilon \cdot \varepsilon ,\end{aligned}$$

and

$$\begin{aligned}P_j = {} & \sigma_{precip} (\alpha_{1,j} + \alpha_{2,j} \cdot \bar{\pi}_{0,j} \\ & + \alpha_{3,j} \cdot OFFFARM + \alpha_{4,j} \cdot TENANT + \alpha_{5,j} \cdot AGE + \alpha_{6,j} \cdot MALE + \alpha_{7,j} \cdot FARMSIZE).\end{aligned}$$

The random variable ε is assumed to be logistically distributed. The parameters to be estimated are the β's, the α's, and σ_ε. In keeping with previous studies on conservation tillage adoption, we included a number of farm operator and farm characteristics (OFFFARM, TENANT, AGE, MALE, and FARMSIZE) that affect adoption decisions, according to the hypotheses in the literature (Sunding and Zilberman 2000).[4] Notice that these characteristics may affect both the expected payoff of conservation tillage and the adoption premium.

Unfortunately, there is high collinearity in the county-level data on farmer characteristics. The presence of the problem can be seen from at least two indicators: high standard errors of coefficients when all variables in question are included in the model, and moment matrix condition numbers, which are 78.85 for the (*OFFFARM*, *TENANT*, *AGE*, *MALE*) group, and 104.75 for the (*OFFFARM*, *TENANT*, *AGE*, *MALE*, and *FARMSIZE*) group.[5]

Table 2 contains the estimation results for several variations of the basic model in equation (4). Because there is a high degree of correlation between FARMSIZE and the other variables, we begin by comparing three models that do not include FARMSIZE. These are (*i*) the unrestricted Model 1 where the explanatory variables OFFFARM, AGE, and MALE appear in both the net returns (the β's) and in the premium (the α's,); (*ii*) the restricted Model 1 in which the explanatory variables OFFFARM, AGE, and MALE appear in the net returns only (not reported); and (*iii*) the restricted Model 2 in which the explanatory variables OFFFARM, AGE, and MALE appear in the premium only. Using a generalized likelihood ratio test, we reject the restricted Model 1 in favor of the unrestricted Model 1 (the computed test statistic 28.2 is greater than the critical value of 16.92 at the 5 percent level of significance), and we fail to reject Model 2 in favor of Model 1 (the computed test statistic 1.13 is clearly less than the critical values at any conventional level of significance). Models 3 and 4 correspond to Models 1 and 2 respectively, with FARMSIZE added as an explanatory variable. Further, we fail to reject Model 4 against the unrestricted Model 3 with a test statistic value of 6.00, again less than the critical values at any conventional level of significance. Overall, Model 4 provides a better fit than does Model 2, as the corresponding generalized likelihood ratio tests reject Model 2 but not Model 4 in favor of the most general model, Model 3.

TABLE 2. Maximum likelihood estimates of the adoption model

Variable(s)	Parameter	Model 1	Model 2	Model 3	Model 4
Net returns to conservation tillage					
I_{cn}	$\beta_{0,cn}$	40*	41*	30*	32*
		(10)	(11)	(13)	(11)
SLOPE	β_1	0.20***	0.22***	0.17	0.13
		(0.11)	(0.12)	(0.13)	(0.11)
PM	β_2	0.59**	0.63**	0.60***	0.50***
		(0.30)	(0.31)	(0.37)	(0.28)
AWC	β_3	0.68**	0.73**	0.71**	0.60**
		(0.29)	(0.29)	(0.36)	(0.25)
TMAX	β_4	2.30*	2.57*	2.8**	2.47*
		(0.76)	(0.68)	(1.2)	(0.63)
TMIN	β_5	-2.25*	-2.48*	-2.9**	-2.46*
		(0.75)	(0.72)	(1.2)	(0.68)
PRECIP	β_6	63	76	105	118***
		(67)	(69)	(88)	(71)
TENANT	β_7	143	194**	27	217**
		(116)	(92)	(168)	(87)
OFFFARM	β_8	-103	_	42	_
		(115)		(166)	
AGE	β_9	-0.1	_	-4.3	_
		(3.2)		(4.5)	
MALE	β_{10}	75	_	172	_
		(170)		(195)	
FARMSIZE	β_{11}	_	_	0.20	_
				(0.18)	
Error Term	σ_ε	5.6*	6.0*	6.5*	5.9*
		(1.7)	(1.6)	(2.5)	(1.5)
Premium					
$\sigma_{precip} \cdot I_{cn}$	$\alpha_{1,cn}$	1271*	1400*	1508**	1416*
		(442)	(411)	(629)	(407)
$\sigma_{precip} \cdot I_{sb}$	$\alpha_{1,sb}$	1017**	1123*	1222**	1162*
		(450)	(432)	(609)	(428)
$\sigma_{precip} \cdot I_{oth}$	$\alpha_{1,oth}$	719	770	681	551
		(536)	(557)	(641)	(521)
$\sigma_{precip} \cdot \overline{\pi}_{0,cn}$	$\alpha_{2,cn}$	-2.79*	-2.79*	-2.72*	-2.77*
		(0.11)	(0.11)	(0.15)	(0.11)

Table 2. Continued

Variable(s)	Parameter	Model 1	Model 2	Model 3	Model 4
$\sigma_{precip} \cdot \bar{\pi}_{0,sb}$	$\alpha_{2,sb}$	-3.30*	-3.32*	-3.26*	-3.21*
		(0.18)	(0.19)	(0.23)	(0.19)
$\sigma_{precip} \cdot \bar{\pi}_{0,oth}$	$\alpha_{2,oth}$	-3.01*	-3.00*	-3.03*	-2.99*
		(0.21)	(0.22)	(0.22)	(0.21)
$\sigma_{precip} \cdot TENANT \cdot I_{cn}$	$\alpha_{3,cn}$	434	607**	-17	582**
		(356)	(274)	(530)	(271)
$\sigma_{precip} \cdot TENANT \cdot I_{sb}$	$\alpha_{3,sb}$	518	682*	143	701*
		(350)	(264)	(501)	(262)
$\sigma_{precip} \cdot TENANT \cdot I_{oth}$	$\alpha_{3,oth}$	288	442	-66	506
		(389)	(339)	(572)	(322)
$\sigma_{precip} \cdot OFFFARM \cdot I_{cn}$	$\alpha_{4,cn}$	-412	-103**	101	–
		(357)	(47)	(509)	
$\sigma_{precip} \cdot OFFFARM \cdot I_{sb}$	$\alpha_{4,sb}$	-429	-131*	41	–
		(355)	(59)	(494)	
$\sigma_{precip} \cdot OFFFARM \cdot I_{oth}$	$\alpha_{4,oth}$	-367	-53	32	–
		(371)	(94)	(533)	
$\sigma_{precip} \cdot AGE \cdot I_{cn}$	$\alpha_{5,cn}$	-5.2	-5.1*	-22	-8.2*
		(9.1)	(1.8)	(15)	(2.4)
$\sigma_{precip} \cdot AGE \cdot I_{sb}$	$\alpha_{5,sb}$	-4.3	-4.0**	-19	-6.3*
		(9.1)	(2.0)	(14)	(2.3)
$\sigma_{precip} \cdot AGE \cdot I_{oth}$	$\alpha_{5,oth}$	-3.3	-2.9	-15	-2.6
		(9.9)	(4.1)	(15)	(4.1)
$\sigma_{precip} \cdot MALE \cdot I_{cn}$	$\alpha_{6,cn}$	-456	-763**	-284	-759**
		(707)	(302)	(801)	(298)
$\sigma_{precip} \cdot MALE \cdot I_{sb}$	$\alpha_{6,sb}$	-314	-605***	-135	-647***
		(710)	(338)	(808)	(334)
$\sigma_{precip} \cdot MALE \cdot I_{oth}$	$\alpha_{6,oth}$	-52	-301	290	-130
		(741)	(469)	(849)	(441)
$\sigma_{precip} \cdot FARMSIZE \cdot I_{cn}$		–	–	0.79	0.183*
				(0.60)	(0.059)
$\sigma_{precip} \cdot FARMSIZE \cdot I_{sb}$		–	–	0.68	0.128**
				(0.56)	(0.053)
$\sigma_{precip} \cdot FARMSIZE \cdot I_{oth}$		–	–	0.55	-0.007
				(0.55)	(0.080)
Fraction of correct		0.71	0.70	0.73	0.73
Log (likelihood)		-778.7	-779.3	-766.5	-769.5

Note: Standard errors are reported in parentheses; they are computed from analytic second derivatives.
*, **, and *** indicate statistical significance at the 1%, 5%, and 10% levels respectively.

Estimates of the effect of soil and climatic conditions on the net returns to conservation tillage are similar among the four models reported and appear reasonable. Land slope (the amount of inclination of the soil surface from the horizontal expressed as the vertical distance divided by the horizontal distance), soil permeability (the rate at which water can pass through a soil material), and available water capacity (the amount of water that a soil can store in a form available for plant use) are all positively related to better drainage of the soil. Improved soil drainage, in turn, is found to positively affect yields under conservation tillage systems (see, for example, Allmaras and Dowdy 1985). The effect of climatic variables on conservation tillage adoption is also robust to the inclusion or exclusion of farm and farmer characteristics and likewise consistent with agronomic science. The signs of the two temperature variables indicate that net returns are higher when the daily temperature variation is higher. The positive effect of precipitation is consistent, with rainfall generally acting as a limiting factor of crop production.[6]

Agronomic studies indicate that a major variable that affects yield uncertainties under both conservation and conventional tillage is the variability of climatic conditions during a crop's growing season (Kaufmann and Snell 1997; Hansen 1991). In this study, we model the climatic variability by way of the variability of precipitation. While the variability of temperature is also important, it often affects the yield variability in conjunction with precipitation variability (Runge 1968). Also, in our study region, areas with higher precipitation variability tend to have higher temperature variability during the crucial periods of the growing season; the sample correlation coefficients between precipitation variability and measures of temperature variability are as high as 0.25. Thus, only the precipitation variability is included in the premium estimation.

The functional form assumed in (4) for the adoption premium guarantees that there is zero premium without the weather variability, as theoretically required. Note that with the inclusion of σ_{precip}, premium P_j is identified separately from profit $\pi_{1,j}$, thus separating the effects of those social economic variables that affect both P_j and $\pi_{1,j}$. While the county-level data available for this study is too aggregated in nature to make strong conclusions about the relationships between the social economic variables and adoption behavior, a few relationships are worth noting.

Farmer's age is found to negatively affect the adoption premium and thus to positively affect the adoption of conservation tillage. *Off-farm employment* is found to reduce the adoption premium, thereby increasing the adoption rate. Since those working off-farm have more diversified sources of income, they may be less risk averse and demand a smaller premium for adoption. Our estimates suggest a negative effect of the proportion of males on the adoption premium.

We find that *tenancy* increases the expected net returns to conservation tillage but also raises the adoption premium. Its overall effect on adoption is negligible, as these two effects roughly cancel each other out. The *returns to conventional tillage* was used as a proxy to farmer's income in the analysis of the premium. The estimated strong negative effect of this variable on the premium is consistent with the presumption of decreasing absolute risk aversion that has found support in many studies of farmers' behavior (see, for example, Moschini and Hennessy 2000). However, similar to the effect of tenancy, the overall effect of this variable on the probability of adoption is about zero at the data means.[7] We find a positive effect of *farm size* on the adoption premium, and thus a negative effect on the probability of adoption.

Adoption Premiums, Subsidies, and Policy Implications

Table 3 presents the estimated adoption payoffs and premiums for the entire sample. The premium accounts for about 13 percent of the annual expected returns to conventional tillage for both major crops. This represents the amount that farmers would need to be paid to compensate them for the uncertainty associated with conservation tillage. If the net return to conservation tillage is greater than the premium, a farmer will adopt with no subsidy. If, however, the net returns are negative, or less than the premium, a subsidy will be required for adoption.

Based on the estimated results, we calculate the subsidies that are needed to induce farmers to adopt conservation tillage. Specifically, given the farmer, soil, and weather characteristics, we calculate the expected net return from conservation tillage, $\hat{\pi}_1$, and the required adoption premium, $\hat{P}$. Let S be the minimum subsidy required for farmers to adopt conservation tillage. If a farmer has already adopted conservation tillage, the

TABLE 3. Estimated Per Acre Adoption Payoff and Premium: Full Sample

Variable	Model 1	Model 2	Model 3	Model 4
Corn				
Premium, $\hat{P}$ ($)	18 (12)	22 (12)	11 (14)	13 (11)
Expected net returns to conservation tillage, $\hat{\pi}_1$ ($)	167 (13)	171 (13)	161 (15)	163 (12)
Percentage of the premium in the expected net returns to conventional tillage, $\hat{P}/\bar{\pi}_0$ (%)	12.5 (8.5)	14.9 (8.5)	7.4 (9.4)	9.3 (7.8)
Soybeans				
Premium, $\hat{P}$ ($)	14 (12)	16 (12)	16 (15)	18 (13)
Expected net returns to conservation tillage, $\hat{\pi}_1$ ($)	127 (10)	130 (13)	131 (16)	132 (13)
Percentage of the premium in the expected net returns to conventional tillage, $\hat{P}/\bar{\pi}_0$ (%)	12 (11)	15 (11)	15 (14)	16 (12)
Other Crops				
Premium, $\hat{P}$ ($)	27 (14)	30 (14)	29 (18)	29 (14)
Expected net returns to conservation tillage, $\hat{\pi}_1$ ($)	118 (13)	120 (14)	118 (16)	119 (14)
Percentage of the premium in the expected net returns to conventional tillage, $\hat{P}/\bar{\pi}_0$ (%)	30 (15)	32 (16)	31 (19)	31 (15)

Note: Estimates are reported at the means of the corresponding samples; standard errors are in parentheses. The standard errors are computed using the Delta method under the assumption of asymptotic normality. We used the subroutine ANALYZE of TSP to compute the standard errors.

required subsidy is zero. Otherwise, the minimum subsidy must satisfy $\hat{\pi}_1 + S = \pi_0 + \hat{P}$. Then we know

$$S = \max\left\{\hat{P} + \left(\pi_0 - \hat{\pi}_1\right), 0\right\}. \tag{5}$$

When S is positive, it can be decomposed into two parts. One part (equal to $\hat{P}$) is used to remove the "hesitancy" of farmers by compensating for their adoption premium, and the remaining part is the monetary transfer to compensate for the profit loss.

Table 4 presents estimates of the premium and mean subsidy evaluated at the sample mean for the subsample of farmers who have not adopted conservation tillage and therefore whose adoption is not expected without a government subsidy. On average, consistent with the extensive agronomic studies, the expected profit of conservation tillage is higher than that of conventional tillage. For example, in Model 4, the projected profit gain of conservation tillage is \$4 per acre for corn and \$38 per acre for soybeans.[8] In the case of such profit gains, why would a farmer not adopt conservation tillage? The answer lies with the adoption premium. The premium is \$7 per acre for corn and \$40 for soybeans, both being higher than the profit gain from conservation tillage. Therefore, either because of risk aversion or real options, the farmer stayed with conventional tillage. That is, the potential gain was not high enough to offset the presence of risk aversion and/or real options.

To induce adoption, the subsidy, which equals the difference between the profit gain and the adoption premium (equation [5]), is \$2.47 per acre per year for corn and \$2.70 for soybeans. Our estimate of the required subsidy is much lower than that estimated by Cooper (1997) (about \$23). Our lower estimates seem reasonable in our study application given that, without any subsidies, about 64 percent of Iowa crop land under corn and 68 percent of that under soybeans is already worked using conservation tillage. Likewise, the subsidy estimates reported here are lower than those reported in Pautsch et al. (2001) because of our more accurate inclusion of a premium and better econometric fit.

Applying equation (5) to each sample point, we calculate the required minimum adoption subsidies for the entire sample. Scaling up the area represented by the sample to the total Iowa agricultural land area, we obtain the state's intensity of adoption at each

TABLE 4. Estimated per acre adoption premium and subsidy: current non-adopters

Variable	Model 1	Model 2	Model 3	Model 4
Corn				
Profit loss due to adoption, $\bar{\pi}_0 - \hat{\pi}_1$ ($)	-9 (13)	-11 (12)	-9 (16)	-4 (12)
Premium, $\hat{P}$ ($)	11 (13)	13 (13)	10 (17)	7 (12)
Subsidy needed for adoption, $\hat{S} = \hat{P} + (\bar{\pi}_0 - \hat{\pi}_1)$ ($)	2.03 (0.88)	2.35 (0.93)	2.7 (1.3)	2.47 (0.94)
Soybeans				
Profit loss due to adoption, $\bar{\pi}_0 - \hat{\pi}_1$ ($)	-35 (15)	-35 (13)	-43 (21)	-38 (14)
Premium, $\hat{P}$ ($)	38 (15)	38 (14)	47 (22)	40 (14)
Subsidy needed for adoption, $\hat{S} = \hat{P} + (\bar{\pi}_0 - \hat{\pi}_1)$ ($)	3.2 (1.3)	3.5 (1.3)	3.7 (1.7)	2.7 (1.2)
Other Crops				
Profit loss due to adoption, $\bar{\pi}_0 - \hat{\pi}_1$ ($)	-21 (14)	-22 (14)	-23 (16)	-24 (14)
Premium, $\hat{P}$ ($)	26 (15)	27 (15)	28 (18)	28 (15)
Subsidy needed for adoption, $\hat{S} = \hat{P} + (\bar{\pi}_0 - \hat{\pi}_1)$ ($)	4.5 (2.2)	4.9 (2.2)	5.0 (2.8)	4.1 (2.0)

Note: Estimates are reported at the means of the corresponding samples; standard errors in parenthesis. We used the subroutine ANALYZE of TSP to compute the standard errors.

subsidy level, or the "supply curve" of conservation tillage, which is presented in Figure 1.[9] Over 14 million acres (about 63 percent of all agricultural land) in Iowa are already in conservation tillage without any subsidy. The acreage increases as the subsidy level rises. At a subsidy of $11.5 per acre, about 90 percent of farmland would be in conservation tillage. Note that the use of the econometrically estimated model allows estimation of the confidence bounds on the supply curve and the subsidy needed to achieve any given level

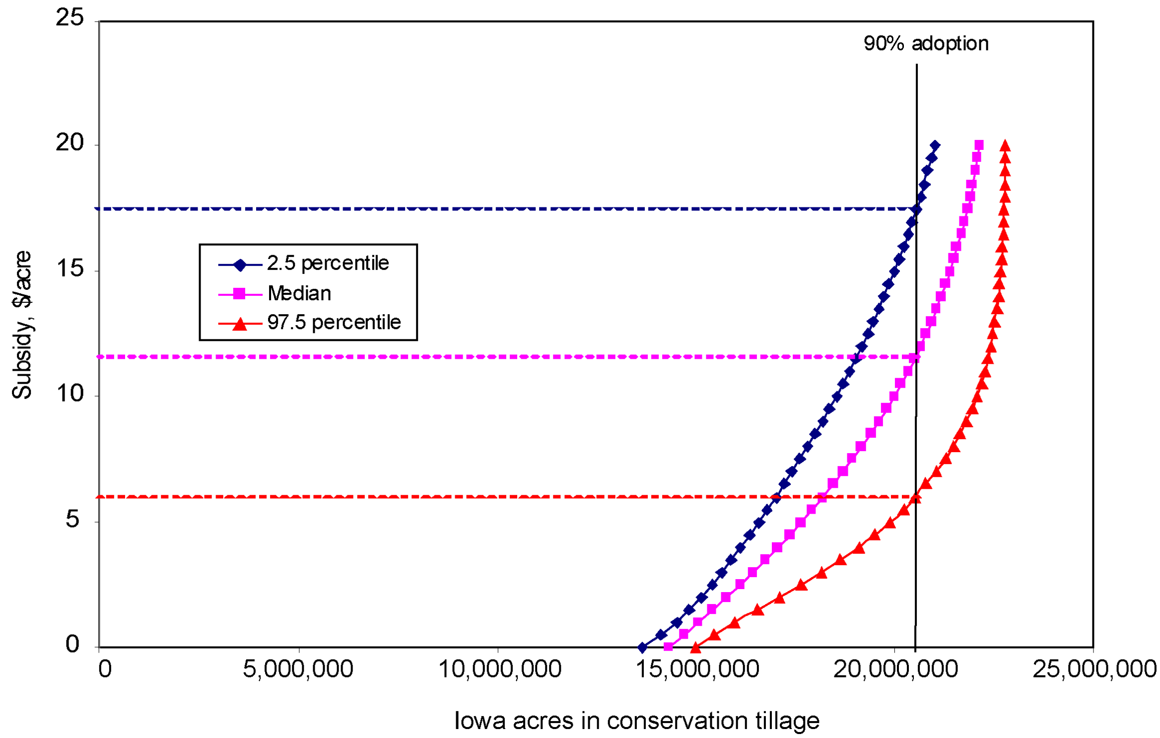

FIGURE 1. Conservation tillage supply curve and the subsidy needed to achieve 90 percent adoption with 95 percent confidence bounds

of adoption. The confidence bounds in Figure 1 are obtained from 10,000 random draws using the methodology of Krinski and Robb (1986).

The supply curve allows us to analyze the nature of a conservation tillage subsidy, in particular, its role as a tool for environmental efficiency or for income transfer. Suppose the government decides to subsidize conservation tillage at $11.5 per acre, for new and existing adopters alike.[10] The subsidy acts as a pure income transfer for existing adopters, as they do not need any additional incentive to adopt. Even for the new adopters, part of the subsidy is, in fact, an income transfer (similar to producer surplus) because of the heterogeneity of the adoption costs. Only the area under the supply curve captures the required compensation for conservation tillage, or serves the single purpose of generating environmental benefits from conservation tillage.

From Figure 2, it is obvious that the income transfer portion of the subsidy far exceeds the efficiency payment component. Of the $237 million total subsidy needed to achieve 90 percent adoption, about $205 million, or over 86 percent, of the total subsidies

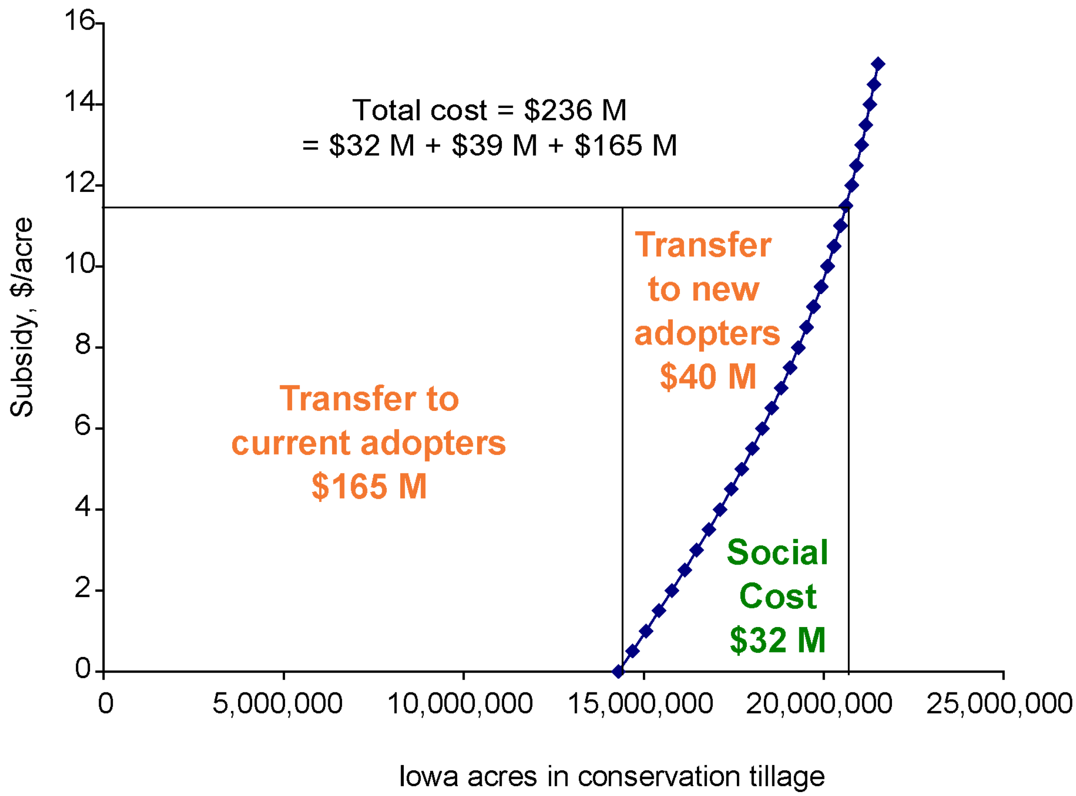

FIGURE 2. Total predicted subsidy cost to achieve 90 percent conservation tillage adoption in Iowa

represents income transfers, a major part of which goes to existing adopters. Using the approach of Krinsky and Robb (1986), the 95 percent confidence interval for the total subsidy is estimated to be [$135 million, $371 million], and that for the income transfers is [$117 million, $320 million].

Conclusion

In this paper, we propose a method of directly estimating the financial incentives for adopting conservation tillage and distinguishing between the expected payoff and the premium of adoption based on observed behavior. We find that the adoption premium may play a significant role in farmers' adoption decisions. Some non-adopters choose not to use conservation tillage because the expected profit gain alone does not fully compensate them for the increased risk and possibility of irreversible lost profits associated with changing from conventional tillage practices. To induce adoption, government subsidies could be used to overcome the adoption premium net of the expected gain from adoption. We find that on average, the mean annual subsidy needed is $2.4 per acre for corn and $3.3 per acre for soybeans.

Information on estimating the adoption subsidy should be helpful to policymakers interested in designing subsidy programs for environmentally friendly agricultural practices. Given appropriate data, the model developed here can be applied to a wide variety of environmentally friendly practices such as drip irrigating, terracing, and using buffer strips.

In this paper, we do not distinguish between the risk aversion and real options forces underlying the adoption premium. However, the distinction is important for policy design because the two possibilities may suggest different optimal policy responses. For example, if risk aversion generates the bulk of the premium, a proper government response may be to offer stabilization policies such as green insurance. However, if irreversibility of sunk investments primarily generates the premium, measures to reduce the option value are more efficient, such as providing better information about conservation tillage or reducing the sunk cost of adoption (e.g., by subsidizing conservation tillage in early years).

Another distinction not explicitly addressed in this model is the use of continuous conservation tillage versus the adoption of conservation tillage for a single year. For some environmental amenities, notably carbon sequestration, a break in the use of conservation till will dissipate most of the accumulated benefits. Consequently, it seems reasonable to enact lower compensation for farmers willing to commit to a single year of conservation tillage and higher compensation for those willing to commit to a longer term. An explicitly dynamic model would be needed to examine this issue.

Endnotes

1. As an exception, Caswell and Zilberman (1986) estimate the premium for adopting new irrigation technologies by relating the costs of technologies to well depth and electricity rates.
2. Readers familiar with the contingent valuation literature will immediately see the similarity between this model and the Cameron bid function approach commonly used to estimate the willingness to pay for an environmental quality change from discrete choice data (Cameron 1988). In the contingent valuation models, the bid offered to respondents in the survey varies across respondents in the same way that the expected net returns from conventional tillage will vary across a sample of farmers. It is this variability that allows identification of the variance of the error in both types of application.
3. Unfortunately, the 1997 and later NRIs did not collect information on tillage practices; hence, more recent NRI data are not available for model estimation.
4. We do not have data on farmers' education, a factor sometimes considered as affecting the adoption decisions. The AGE variable turned out to be highly correlated (coefficient of correlation 0.67 with a p-value of less than 0.0001) with PRESENCE, the average years present on the farm, another variable available in the Census of Agriculture. The model estimated with the PRESENCE variable is neither quantitatively nor qualitatively different from the mode with AGE and therefore is not presented here.
5. Belsley, Kuh, and Welsch (1980) argue that values above 20 suggest potential problems.
6. Several other alternative model specifications were considered but were found to provide inferior fits. Specifically, the intercept term, β_0, was initially allowed to vary for every crop, but the estimates were not significant for soybeans and for other crops. We also initially modeled the error term as heteroskedastic across crops, but

the generalized likelihood ratio test failed to reject the hypothesis that the error term is homoskedastic. The computed test statistics, 3.72 for Model 2 and 2.44 for Model 4, do not exceed the critical value of 5.99 at the 5 percent level of significance.

7. The derivative of the probability of adoption with respect to $\overline{\pi}_0$ is proportional to $1+\sigma_{precip}\cdot(\alpha_{2,cn}\cdot I_{cn}+\alpha_{2,sb}\cdot I_{sb}+\alpha_{2,oth}\cdot I_{oth})$.
8. Of course, there are farmers for whom the expected net returns are lower under conservation tillage. They will not adopt even if their adoption premiums are zero.
9. Figure 1 is constructed using Model 4 results. Other models reported provide essentially the same results.
10. The government may choose to subsidize new adopters only, but the feasibility of such a policy is questionable, as some have argued that it punishes “good stewards” of farmland.

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